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Front End Electronics for Calorimetry in Space

AMS02-ECAL collaboration

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A front end read-out electronic system has been developed for the electromagnetic calorimeter (ECAL) of the AMS experiment [1]. AMS will be installed on the International Space Station (ISS) and will record several billions cosmic rays per year of operation. The ECAL front-end read-out was designed with a dynamic range of 60,000 to measure minimum ionizing particles and high energy (more than 1 TeV) electromagnetic showers as well.

1. Introduction

The 3D imaging electromagnetic calorimeter (ECAL) consists of 9 modules made of a sandwich of grooved lead foils and of layers of scintillating fibers glued together [2]. The fibers are read alternatively at one end or the other by 324 4-anodes square PMT's. The PMTs with their electronics are housed with the light guide system into a polycarbonate support tube. As the detector will be operated in space, the electronics must be a low power consumption device, must sustain vibrations and must be able to work in vacuum with temperatures from -30° to $+40^{\circ}$. The system comprises also an analog topological trigger for the detection of gamma-ray showers. It will be described in detail with the main challenges encountered to meet the required physics performances.

2. The Front End Readout Electronics

The light collection and readout system must process signals with a good linearity over a wide dynamic range, from a minimum ionizing particle, which produces about 8 photoelectrons per cell, up to the 6×10^4 photoelectrons produced in one cell by the electromagnetic showering of a 1 TeV electron. To fulfil this requirement, the high voltages for the PMT are provided by a tapered resistor divider (1.5:1.5:1.5:1:1:1:1:2: 3.7) which allows also to reduce the power consumption to 100 mW at the nominal working point of 650 V.

To insure a dynamic range of 60000, the PMT signals from the 4 anodes are splitted into two sub ranges by voltage dividers and read out by two electronics channels with a gain ratio of about 33, see Figure 2. This electronics was implemented in a dedicated ASIC chip [3] in BiCMOS 0.8 microns technology with very low power consumption (21 mW in total). The layout of the ASIC is represented together with the different functional blocks in Figure 1.

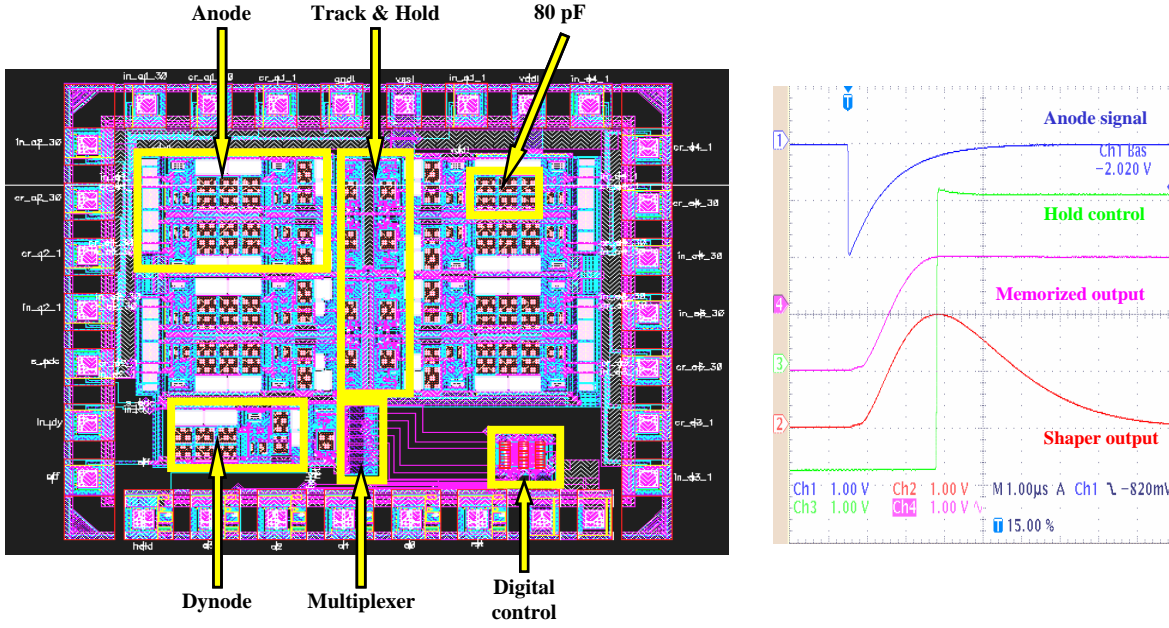


Figure 1: A full custom CMOS chip, a drawing of the layout (left) and the different outputs and sequences of the readout electronics superimposed with the anode signal (right) .

The signal of the last dynode of the PMT is also read out and simultaneously sent to a low gain electronic channel in the chip for redundancy purpose and amplified and sent to a comparator for the analog gamma trigger. The signals in the 9 channels of the chip (2x4 anodes + 1 dynode) are shaped to give a peaking time around 2.2 μs and are hold until they are read via a multiplexing circuit and sent sequentially to a serial ADC (AD7476A, also used by other sub-detectors). The HV dividers are implemented on two $26 \times 26 \text{ mm}^2$ board, and a third board $30 \times 30 \text{ mm}^2$ accommodates the chip and the ADC. All 3 boards are assembled together and mounted behind each PMT as depicted on Figure 2. The bases and the rear of the PMT are completely potted to avoid corona effect while the Front-End board is only coated to save weight. The digitized outputs from 9 PMT's are sent via an intermediate board (EIB) to the off detector electronics, as described in section 3.

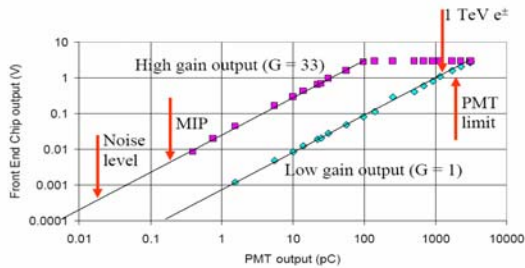


Figure 2: Left: The output signal of the Front End readout Chip measurements for different input signals (in pC); The full dynamic range expected is given as well as the overlap between the two gain channels. right: A fully equipped readout system, including the two High Voltage divider boards and the EFE (last board); All the components and cables are space qualified. The ASIC chip has been qualified for space. The PMT's block is potted using silicon material.

On July 2002, the Engineering Model of ECAL was exposed to the CERN SPS beam line H6A using muons, electrons and protons with energy range from 3 to 180 GeV. The calorimeter was partially equipped with 63 PMT's, resulting in a $126 \times 126 \text{ mm}^2$ active surface in one ECAL corner. The high voltage supply for each PMT was set individually to work at a gain of about 2×10^5 . The MIP signal, well-separated from the noise level, as shown in Figures 3, has been used to inter-calibrate the anodes of the 63 Pmts.

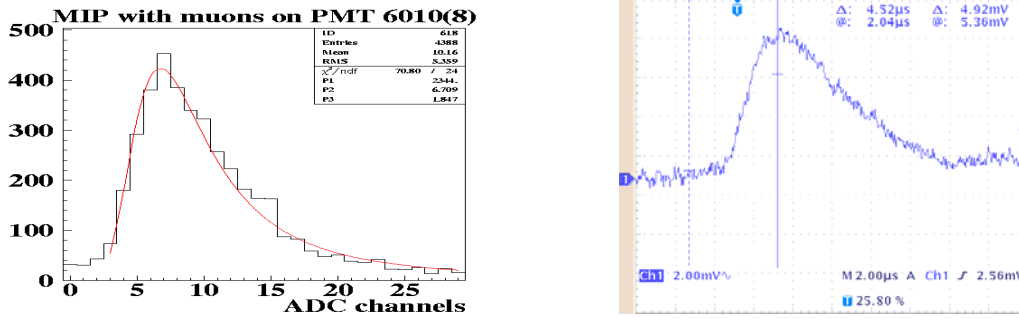


Figure 3 : The MIP signal simulated on the electronic test bench (right) or measured (left) on the test beam, was found to be in average at ~ 6 ADC channels, as expected.

During those tests, it was shown that the ECAL performance (linearity, energy and angular resolution, e/p discrimination [4]) are in good agreement with the expectations and fulfil the physics requirements. The measured energy resolution is $\sigma(E)/E = (10.2 \pm 0.3)\% / \sqrt{E} \oplus (2.3 \pm 0.1)\%$.

3. The analog Trigger

The ECAL is included in the global trigger for detecting γ and to identify electrons. The constraints are the following: the decision of the fast ECAL trigger should be given within 180 ns, the additional trigger rate should be less than 50 Hz (compared to the maximal value of 2 kHz) and the power consumption below 10 Watts. During the 2002 test beam, it was demonstrated that the last dynode signal after amplification can be used in a fast standalone trigger for photons with energies above 2 GeV. The trigger decision is build into 2 steps: a fast decision, available within 180 ns, given by the count of PMTs above threshold in the 6 central superlayers of the calorimeter; a level 1 trigger decision, well before 1 μ s, obtained with a fast reconstruction of the particle direction.

The function of the EIB is twofold: it treats the analog signals from dynodes for the ECAL standalone trigger [5] and it insures the Data transfer from the EFE to the DAQ system via the EDR board (Ecal Reduction Board) [6] as well as the low power supply and logic signals transfers from the EDR to the EFE. There is in total 36 EIB boards, splitted into 4 EIB's per superlayer, which represents a granularity of 9 PMTs per EIB. To summarize, in total 24 EIBs are included in the ECAL standalone trigger. The schematic of the analog trigger part is shown in Figure 4: the analog signal is amplified by a factor 10, in order to get a signal amplitude

The circuit diagram shows the signal path from the FEU dynode to the DAQ. The dynode signal (DY10_TRIG1) is coupled through a 100nF capacitor to the input of an INA826 instrumentation amplifier. The amplifier is configured with a 1.00k resistor and a 1.00k resistor. The output of the amplifier is connected to a 100k resistor and a 1.00k resistor. The signal is then processed by a 5M74LVC1G125 monostable multivibrator, which is configured with a 1.2k resistor and a 330pF capacitor. The output of the multivibrator is connected to a 100k resistor and a 1.00k resistor. The signal is then processed by a 5M74LVC1G125 monostable multivibrator, which is configured with a 1.2k resistor and a 330pF capacitor. The output of the multivibrator is connected to a 100k resistor and a 1.00k resistor. The signal is then processed by a 5M74LVC1G125 monostable multivibrator, which is configured with a 1.2k resistor and a 330pF capacitor. The output of the multivibrator is connected to a 100k resistor and a 1.00k resistor.

The histogram shows the distribution of the FEU dynode signal in mV. The x-axis ranges from 0 to 100 mV, and the y-axis ranges from 0 to 400 events. The distribution is a single peak centered around 10 mV, with a tail extending to 100 mV.

The discrete components (mainly the comparator and the amplifier) have been chosen in order to fulfil the timing and consumption constraints [5]. It appears that for signals close to the threshold, the delay between the dynode and the flipflop output is less than 100ns while for larger signals (at least 50 mV above the threshold) it becomes shorter, typically 50 ns. The analog trigger performances have been measured at CERN in September 2004 using electron and pion beams with energy range from 3 to 7 GeV. The setup consisted of two EIBs equipped with 9 PMTs each. Different thresholds have been tested, ranging from 10 mV to 500 mV. Results concerning the comparison of the events with or without trigger, for a threshold of 100 mV, are illustrated on Figure 4. The efficiency has been measured for each threshold, for each channel. The random trigger rate has been also measured and is found to be less than 0.7 ‰ [7].

A front-end electronics has been developed for calorimetry in space. The EFE boards are now produced and have passed successfully the radiation, vibration, production and thermal vacuum tests. The first qualified model boards of the EIB are scheduled for fall 2005, and the production will start at the end of 2005. The ECAL construction schedule is fully satisfactory and the ECAL is expected to be ready for calibration tests in 2006 and ready for launch at the beginning of 2007.

5. References

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